

FORM PTO-1390 (Modified)
(REV 10-95)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 3719847-0056-6X PCT *PCT*

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

09/554954

INTERNATIONAL APPLICATION NO.
PCT/EP98/07738INTERNATIONAL FILING DATE
30 NOVEMBER 1998PRIORITY DATE CLAIMED
28 NOVEMBER 1997

TITLE OF INVENTION

HIGH VOLTAGE ROTATING ELECTRIC MACHINES

APPLICANT(S) FOR DO/EO/US

Mats LEIJON

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report

Notice of Priority

Marked-up Copy of Specification

Form PTO-1449

Response to Petition Under 37 CFR 1.182

List of Related Cases

U.S. APPLICATION NO. IF KNOWN, SEE 37 CFR

09/354954

INTERNATIONAL APPLICATION NO.

PCT/EP98/07738

ATTORNEY'S DOCKET NUMBER

9847-0056-6X PCT

20. The following fees are submitted:

CALCULATIONS PTO USE ONLY

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

- ☒ Search Report has been prepared by the EPO or JPO \$840.00
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) \$670.00
- ☐ No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) \$760.00
- ☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$970.00
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) \$96.00

ENTER APPROPRIATE BASIC FEE AMOUNT =**\$840.00**

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).

\$130.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	50 - 20 =	30	x \$18.00
Independent claims	3 - 3 =	0	x \$78.00

\$540.00**\$0.00**Multiple Dependent Claims (check if applicable). ☐**\$0.00****TOTAL OF ABOVE CALCULATIONS =****\$1,510.00**

Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable). ☐

\$0.00**SUBTOTAL =****\$1,510.00**

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).

\$0.00**TOTAL NATIONAL FEE =****\$1,510.00**

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). ☐

\$0.00**TOTAL FEES ENCLOSED =****\$1,510.00**

Amount to be:

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☒ A check in the amount of **\$1,510.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees.
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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REGISTRATION NUMBER 30,996

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NAME

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REGISTRATION NUMBER

DATE

May 22, 2000

09/554954

526 Rec'd PCT/PTO 22 MAY 2000

9847-0056-6X PCT
ENKEL 8357

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:

MATS LEIJON

: ATTN: APPLICATION DIVISION

SERIAL NO: NEW APPLICATION
(BASED ON PCT/EP98/07738)

FILED: HERewith

FOR: HIGH VOLTAGE ROTATING ELECTRIC
MACHINES

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, DC 20231

SIR:

Prior to examination on the merits, please amend the above-identified patent application
as follows:

IN THE CLAIMS

Please cancel without prejudice or disclaimer Claims 1-45.

Please add new Claims 46-95 as follows:

--46. A high voltage rotating electric machine comprising:

a stator;

a rotor; and

a winding having

an inner electrically conducting material formed as a conductor, and

a cooling mechanism configured to cool said conductor to improve an electrical

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conductivity of said conductor, and

a surrounding electrical insulation being solid and having

a semiconducting inner layer,

a semiconducting outer layer, and

an intermediate layer of electrically insulating material positioned between
said semiconducting inner layer and said semiconducting outer layer.

47. A high voltage rotating electric machine according to claim 46, wherein:

said semiconducting inner layer being electrically connected to the conductor so as to be
at a same electric potential as said conductor.

48. A high voltage rotating electric machine according to claim 46, wherein:

said semiconducting outer layer being connected along a length thereof to a node held at
a controlled electric potential.

49. A high voltage rotating electric machine according to claim 48, wherein:

said semiconducting outer layer being connected at spaced apart regions to said node.

50. A high voltage rotating electric machine according to claim 48, wherein:

said controlled electric potential being earth potential.

51. A high voltage rotating electric machine according to claim 46, further
comprising:

another winding; wherein

a separate controlled potential being selected for each of said winding and said another

winding.

52. A high voltage rotating electric machine according to claim 46, wherein:

at least one of said semiconducting inner layer and said semiconducting outer layer having a substantially equal coefficient of thermal expansion as that of said intermediate layer of electrically insulating material.

53. A high voltage rotating electric machine according to claim 46, comprising:

at least one pair of adjacent layers of said inner layer, said intermediate layer, and said outer layer being secured to each other along substantially respective contact surfaces.

54. A high voltage rotating electric machine comprising:

at least one magnetic circuit having

a magnetic core; and

a winding having

a cable having

an inner electrical conductor,

a cooling mechanism configured to cool said electrical conductor

so as to improve an electrical conductivity of said electrical conductor, and

an outer solid electrical insulation having

a semiconducting inner layer,

a semiconducting outer layer, and

an intermediate layer of electrically insulating material

positioned between said semiconducting inner layer and said semiconducting outer layer.

55. A high voltage rotating electric machine according to claim 54, further comprising:
a stator,
said at least one magnetic circuit being disposed in the stator.

56. A high voltage rotating electric machine according to claim 54, further comprising:
a rotor,
said at least one magnetic circuit being disposed in the rotor.

57. A high voltage rotating electric machine according to claim 54, wherein:
said semiconducting outer layer being connected to a node at earth potential at spaced apart
regions along a length thereof.

58. A high voltage rotating electric machine according to claim 57, further comprising:
slots, and
an end winding region wherein
when said semiconducting outer layer being connected to earth potential, an electric field
of said high voltage rotating electric machine at both said slots and said end winding region being
near zero.

59. A high voltage rotating electric machine according to claim 54, wherein:
said electrical conductor including a superconducting material.

60. A high voltage rotating electric machine according to claim 59, wherein:
said cooling mechanism having a central tubular support configured to convey a
cryogenic coolant fluid, and

said superconducting material being wound around said central tubular support.

61. A high voltage rotating electric machine according to claim 60, wherein:

said cryogenic coolant fluid being liquid nitrogen.

62. A high voltage rotating electric machine according to claim 59, wherein:

said superconducting material includes at least one of a high-transition temperature superconducting material and a high-transition temperature HTS material.

63. An electric machine according to claim 62, wherein:

said high-transition temperature HTS material includes at least one of a HTS tape and a wire wound around said tubular support.

64. A high voltage rotating electric machine according to claim 54, further comprising:

a thermal expansion mechanism provided between said inner electrically conducting material and said electrical insulation.

65. A high voltage rotating electric machine according to claim 64, wherein:

said thermal expansion mechanism being an expansion gap.

66. An electric machine according to claim 65, wherein:

said thermal expansion gap being a void space.

67. A high voltage rotating electric machine according to claim 65, wherein:

said thermal expansion gap being filled with a compressible material.

68. A high voltage rotating electric machine according to claim 67, wherein:

said compressible material being a foamed plastics material.

69. A high voltage rotating electric machine according to claim 67, wherein:

said compressible material includes at least one of an electrically conductive material and a semiconductive material.

70. A high voltage rotating electric machine according to claim 54, further comprising:

a thermally insulating material being provided outwardly of said electrical conductor.

71. A high voltage rotating electric machine according to claim 55, wherein:

said winding being wound in at least one slot formed in said stator, and

each of said at least one slot having

a plurality of substantially circular cylindrical openings extending axially and radially outside one another,

at least one pair of adjacent openings being joined by a narrower waist portion.

72. A high voltage rotating electric machine according to claim 56, wherein:

said winding being wound in at least one slot formed in said rotor, and

each of said at least one slot having

a plurality of substantially circular cylindrical openings extending axially and radially outside one another,

at least one pair of adjacent openings being joined by a narrower waist portion.

73. A high voltage rotating electric machine according to claim 71, wherein:
a radii of said plurality of substantially circular cylindrical openings decrease in a direction away from a yoke portion of a laminated core of said stator.

74. A high voltage rotating electric machine according to claim 72, wherein:
a radii of said plurality of substantially circular cylindrical openings decrease in a direction away from a yoke portion of a laminated core of said stator.

~~75. A high voltage rotating electric machine comprising:~~
a stator;
a rotor; and
a winding having a coil with
a conductor,
a cooling mechanism configured to cool said conductor so as to improve an electrical conductivity of said conductor,
a layer of electrical insulation surrounding said conductor, and
an equipotential outer layer surrounding said electrical insulation.

76. A high voltage rotating electric machine according to claim 75, wherein:
said conductor having a superconducting material.

77. A high voltage rotating electric machine according to claim 75, wherein:
said winding being connectable to at least one system voltage level.

78. A high voltage rotating electric machine according to claim 77, wherein:
said winding being provided with separate tapplings for connection to different system
voltage levels.

79. A high voltage rotating electric machine according to claim 77, wherein:
a separate winding being provided for connection to each level of said at least one system
voltage level.

80. A high voltage rotating electric machine according to claim 75, further comprising:
an inner semiconducting layer disposed between said conductor and said intermediate
layer of electrical insulation.

81. A high voltage rotating electric machine according to claim 80, wherein:
said intermediate layer of electrical insulation being joined to each of said inner
semiconducting layer and said equipotential outer layer.

82. A high voltage rotating electric machine according to claim 81, wherein:
a strength of an adhesion between said intermediate layer of electrical insulation and
each of said inner semiconducting layer and said equipotential outer layer being of a same
order of magnitude as an intrinsic strength of a material of said intermediate layer of electrical
insulation.

83. A high voltage rotating electric machine according to claim 80, wherein:
said inner semiconducting layer, said equipotential outer layer and said intermediate layer
of electrical insulation being joined together by extrusion.

84. A high voltage rotating electric machine according to claim 83, wherein:

said inner semiconducting layer, said equipotential outer layer and said intermediate layer of electrical insulation being applied together over said conductor through a multi-layer extrusion die.

85. A high voltage rotating electric machine according to claim 80, wherein:

said inner semiconducting layer having

a first plastics material having first electrically conductive particles dispersed therein;

said equipotential outer layer having

a second plastics material having second electrically conductive particles dispersed therein; and

said intermediate layer of electrical insulation having a third plastics material.

86. A high voltage rotating electric machine according to claim 85, wherein:

each of said first plastics material, said second plastics material and said third plastics material comprising at least one of an ethylene butyl acrylate copolymer rubber, an ethylene-propylene-diene monomer rubber (EPDM), an ethylene-propylene copolymer rubber (EPR), LDPE, HDPE, PP, PB, PMP, XLPE, EPR, and a silicone rubber.

87. A high voltage rotating electric machine according to claim 85, wherein:

said first plastics material, said second plastics material and said third plastics material having a substantially same coefficient of thermal expansion.

88. A high voltage rotating electric machine according to claim 85, wherein:
said first plastics material, said second plastics material and said third plastics material
being a same material.

89. A high voltage rotating electric machine according to claim 75, further comprising:
an electric field containing means being for containing an electric field associated
with a high voltage on said flexible conductor in excess of 36 kV.

90. A high voltage rotating electric machine according to claim 75, further
comprising: _____
an electric field containing means being for handling a power in excess of 0.5 MVA.

91. A high voltage rotating electric machine according to claim 75, wherein:
said winding being configured to operate with a 100% overload for a time in an inclusive
range of 15 minutes through two hours.

92. A high voltage rotating electric machine according to claim 75, wherein:
said winding being configured to be directly connected to a power network via
connecting devices and without an intermediate transformer between said high voltage
rotating electric machine and said power network.

93. A high voltage rotating electric machine according to claim 75, further
comprising:
a means for regulating a voltage of said high voltage rotating electric machine by control
of a magnetic field flow through said rotor.

94. A high voltage rotating electric machine according to claim 92, wherein:

said high voltage rotating electric machine being configured to be operated without a mechanical load and including means for compensating for at least one of inductive load and capacitive load on said power network.

95. A high voltage rotating electric machine according to claim 55, wherein:

said winding being wound in at least one slot formed in said stator and including means for confining an electric field, and

each of said at least one slot having

a plurality of substantially circular cylindrical openings extending axially and radially outside one another,

at least one pair of adjacent openings being joined by a narrower waist portion.--

IN THE ABSTRACT OF THE DISCLOSURE

After the last page of the specification, please insert the following Abstract of the Disclosure.

--ABSTRACT OF THE DISCLOSURE

A rotating electric machine for direct connection to all types of high-voltage networks, in which the magnetic circuit adapted for high voltage has a rotor, a stator, and at least one winding. The winding, or at least one of the windings, has a cooled conductor, preferable a cooled superconductor, surrounded by a solid insulation system.--

REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested. Claims 46-95 are pending, Claims 1-45 having been canceled without prejudice or disclaimer and Claims 46-95 having been added by way of the present amendment. New Claims 46-95 find support in original Claims 1-45, and thus add no new matter. An Abstract has been added, consistent with U.S. patent drafting procedure.

Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a substitute specification is filed herewith in addition to a marked-up copy of the original application. Please enter this substitute specification. To the extent any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes should be construed as typographical errors and the language included in the originally-filed PCT application should be construed as containing the controlling language.

The present document is one of a set of patent applications containing related technology as was discussed in "response to petition under 37 C.F.R. §1.182 seeking special treatment relating to an electronic search tool, and decision on petition under 37 C.F.R. §1.183 seeking waiver of requirements under 37 C.F.R. §1.98," filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an Information Disclosure Statement is filed herewith including a PTO Form 1449 with references that are included as part of the specially-created official digest in class 174. It is believed that submission of these materials and the reference to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with the decision.

In view of the present amendment and in light of the foregoing comments, an examination on the merits is believed to be in order and an early and favorable action is respectfully requested.

Respectfully submitted,

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High Voltage Rotating Electric MachinesTECHNICAL FIELD

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This invention relates to a rotating electric machine and in particular to a rotating electric machine with at least one magnetic circuit comprising a magnetic core and a winding. Examples of such rotating electric machines to which the invention relates are synchronous machines which are mainly used as generators for connection to distribution and transmission networks, commonly referred to below as "power networks". Other uses of synchronous machines are as motors and for phase compensation and voltage control, e.g. as mechanically idling machines. Other rotating electric machines to which the invention relates are double-fed machines, asynchronous machines, asynchronous converter cascades, outer pole machines and synchronous flux machines.

The magnetic circuit of a rotating electric machine referred to in this context comprises a magnetic core of laminated, normal or oriented, sheet material or other, for example amorphous or powder-based, material, or any other device providing a closed path of alternating magnetic flux. The magnetic circuit may also include a winding, a cooling system, etc., and may be located in the stator of the machine, the rotor of the machine, or in both the stator and the rotor.

BACKGROUND ART

25 A magnetic circuit of a conventional rotating electric machine in the form of a synchronous machine is, in most cases, located in the stator of the machine. Such a magnetic circuit is normally described as a stator with a laminated core, the winding of which is referred to as a stator winding, and the slots in the laminated core for the winding are referred to as stator slots or simply slots.

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Most synchronous machines have a field winding in the rotor, where the main flux is generated by dc, and an ac winding which is in the stator. Synchronous machines are normally of three-phase design and may be designed with 5 salient poles. This latter type of synchronous machine have an ac winding in the rotor.

The stator body for a large synchronous machine is often constructed from welded together sheet steel. The laminated core is normally made from varnished 0.35 or 0.5 mm thick 10 laminations. For larger machines, the sheet is punched into segments which are attached to the stator body by means of wedges/dovetails. The laminated core is retained by pressure fingers and pressure plates.

Three different cooling systems are available to cool 15 the windings of the synchronous machine. With air cooling, both the stator winding and the rotor winding are cooled by cooling air flows. Cooling air ducts are provided both in the stator laminations and in the rotor. For radial ventilation and cooling by means of air, the sheet iron core, at least for 20 medium-sized and large machines, is divided into stacks with radial and axial ventilation ducts disposed in the core. The cooling air may consist of ambient air but at powers exceeding 1 MW, a closed cooling system with heat exchangers is often used.

25 Hydrogen cooling is normally used in turbogenerators up to about 400 MW and in large synchronous condensers. This cooling method functions in a manner similar to air cooling with heat exchangers, but instead of air as coolant, hydrogen gas is used. The hydrogen gas has better cooling capacity 30 than air, but difficulties arise at seals and in monitoring leakage.

For turbogenerators having a power range of 500-1000 MW, it is known to apply water cooling to both the stator winding and the rotor winding. The cooling ducts are in the form of

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tubes which are placed inside conductors in the stator winding.

One problem with large machines is that the cooling tends to become non-uniform resulting in temperature differences arising across the machine.

The stator winding is located in slots in the sheet iron core, the slots normally having a rectangular or trapezoidal cross section. Each winding phase comprises a number of coil groups connected in series with each coil group comprising a number of coils connected in series. The different parts of the coil are designated the "coil side" for the part which is placed in the stator and the "end winding" for that part which is located outside the stator. A coil comprises one or more conductors brought together in height and/or width.

Between each conductor or conductor turn of a coil there is a thin insulation, for example epoxy/glass fibre.

The coil is electrically insulated from the slot by coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to earth. As insulating material, various plastics materials, varnish and glass fibre materials are conventionally used. Usually, so-called mica tape is used, which is a mixture of mica and hard plastics material, especially produced to provide resistance to partial discharges, which can rapidly break down the electrical insulation. The insulation is applied to the coil by winding several layers of the mica tape around the coil. The insulation is impregnated, and the coil side is painted with a graphite based paint to improve the contact with the surrounding stator which is connected to earth potential.

The conductor area of the windings is determined by the current intensity in question and by the cooling method used. The conductor and the coil are usually of a rectangular shape to maximise the amount of conductor material in the slot. A

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typical coil is formed of so-called Roebel bars, in which some of the bars are made hollow for a coolant. A Roebel bar comprises a plurality of rectangular, copper conductors connected in parallel, which are transposed 360 degrees along the slot. Ringland bars with transpositions of 540 degrees and other transpositions also occur. The transposition is made to avoid the occurrence of circulating currents which are generated in a cross section of the conductor material, as viewed from the magnetic field.

10 For mechanical and electrical reasons, a machine cannot be made of just any size. The machine power is determined substantially by three factors:

- The conductor area of the windings. At normal operating temperature, copper, for example, has a maximum value of from 15 3 to 3.5 A/mm².

- The maximum flux density (magnetic flux) in the stator and rotor material.

- The maximum electric field strength in the electrical insulation, the so-called dielectric strength.

20 Polyphase ac windings are designed either as single-layer or two-layer windings. In the case of single-layer windings, there is only one coil side per slot, and in the case of two-layer windings there are two coil sides per slot. Two-layer windings are usually designed as diamond windings, 25 whereas the single-layer windings which are relevant in this connection may be designed as a diamond winding or as a concentric winding. In the case of a diamond winding, only one coil span (or possibly two coil spans) occur, whereas flat windings are designed as concentric windings, that is, with 30 a greatly varying coil span. By "coil span" is meant the distance in circular measure between two coil sides belonging to the same coil, either in relation to the relevant pole pitch or in the number of intermediate slot pitches. Usually,

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different variants of chording are used, for example short-pitching, to give the winding the desired properties.

The type of winding substantially describes how the coils in the slots, that is, the coil sides, are connected together outside the stator, that is, at the end windings.

Outside the stacked sheets of the stator, the coil is not provided with a painted semiconducting ground-potential layer. The end winding is normally provided with an E-field control in the form of so-called corona protection varnish intended to convert a radial field into an axial field, which means that the insulation on the end windings occurs at a high potential relative to earth. This sometimes gives rise to corona discharges in the coil-end region, which may be destructive. The so-called field-controlling points at the end windings entail problems for a rotating electric machine.

Normally, all large machines are designed with a two-layer winding and equally large coils. Each coil is placed with one side in one of the layers and the other side in the other layer. This means that all the coils cross each other in the end winding. If more than two layers are used, these crossings render the winding work difficult and deteriorate the end winding.

It is generally known that the connection of a synchronous machine/generator to a power network must be made via a Δ /D-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Together with the synchronous machine, this transformer thus constitutes integrated parts of a plant. The transformer constitutes an extra cost and also has the disadvantage that the total efficiency of the system is lowered. If it were possible to manufacture machines for considerably higher voltages, the step-up transformer could thus be omitted.

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During the last few decades, there has been an increasing demand for rotating electric machines of higher voltages than it has previously been possible to design. The maximum voltage level which, according to the state of the art, has been possible to achieve for synchronous machines with a good yield in the coil production is around 25-30 kV.

Certain attempts to a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US-A-4,429,244 "Stator of Generator" and in Russian patent specification CCCP 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured in rectangular section slots by wedges. Oil is used as a coolant both in the hollow conductors and in holes in the stator walls. Such cooling systems, however, require a large number of connections of both oil and electricity at the coil ends. The need for thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

US-A-4,429,244 relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered because there is less need for electrical insulation of the stator winding towards the rotor

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where the part of the winding nearest to the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core. This part may increase the magnetization requirement relative to a machine without such a cylinder. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. What is special for the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centred, inside an insulating sleeve and conductors of the stator winding are cooled by surrounding oil. Disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulating sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the purpose of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage cable with the same dimensions for all the layers. The cable is placed in stator slots formed as circular, radially located openings corresponding to the cross-sectional area of the cable and the necessary space for fixing and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulating tubes. Insulating spacers fix the tubes in the stator slot. Because of oil cooling, an internal dielectric ring is also needed to seal the oil coolant from the internal air gap. The disadvantages of oil in the system described above also apply to this design. The design also exhibits a very narrow radial waist between the different stator slots, which implies a large slot leakage flux which significantly influences the magnetization requirement of the machine.

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A report from Electric Power Research Institute, EPRI, EL-3391, from 1984 describes a review of machine concepts for achieving a higher voltage of a rotating electric machine for the purpose of connecting a machine to a power network without an intermediate transformer. Such a solution is said to provide good efficiency gains and great economic advantages. The main reason for considering in 1984 the development of generators for direct connection to power networks was that at the time a superconducting rotor had been produced. The large magnetization capacity of the superconducting field makes it possible to use an air gap winding with a sufficient insulation thickness to withstand the electrical stresses. By combining the most promising concept, according to the project, of designing a magnetic circuit with a winding, a so-called monolith cylinder armature, a concept where the winding comprises two cylinders of conductors concentrically enclosed in three cylindrical insulating casings and the whole structure being fixed to an iron core without teeth, it was judged that a rotating electric machine for high voltage could be directly connected to a power network. The solution meant that the main insulation had to be made sufficiently thick to cope with network-to-network and network-to-earth potentials. The insulation system which, after a review of all the technique known at the time, was judged to be necessary to manage an increase to a higher voltage was that which is normally used for power transformers and which consists of dielectric-fluid-impregnated cellulose pressboard. Obvious disadvantages with the proposed solution are that it requires a very thick insulation which increases the size of the machine. The end windings must be insulated and cooled with oil or freon to control the large electric fields in the ends. The whole machine must be hermetically enclosed to prevent the liquid dielectric from absorbing moisture from the atmosphere.

During the decades around 1930 a few generators with high voltages up to 36 kV were built in order to develop a generator for direct connection to power networks. One

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project was based on using conductors of concentric type, with three layers of conductors enclosed in insulation, where each layer was connected in series and the inner layer was at the highest potential. In another version the electrical
5 conductors were made of twisted copper strips that were isolated with special layers of mica, varnish and paper.

When manufacturing rotating electric machines according to the state of the art, the winding is manufactured with conductors and insulation systems in several steps, whereby
10 the winding must be preformed prior to mounting in the magnetic circuit. Impregnation for preparing the insulation system is performed after mounting of the winding in the magnetic circuit.

SUMMARY OF THE INVENTION

15 An aim of the present invention is to obtain a rotating electric machine with such a high voltage that the use of a step-up transformer mentioned above can be omitted, that is, machines with a considerably higher voltage than machines according to the state of the art can be connected directly
20 to power networks. This means considerably lower investment costs for systems with a rotating electric machine and the total efficiency of the system can be increased.

The rotating electric machine can be connected to a power network with a minimum of connecting devices such as
25 circuit breakers, disconnectors or the like. In a system with a rotating machine directly connected to a power network without an intermediate transformer the connection can be made using only one circuit breaker.

A further aim of the present invention is to provide an
30 electrical machine having at least one winding including conducting means which have improved electrically conducting properties at low temperatures and cooling means for cooling

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the conducting means below normal ambient operating temperatures and preferably to at least 200 K.

According to one aspect of the present invention, there is provided a high voltage rotating electric machine as
5 claimed in the ensuing claim 1.

According to other aspects of the present invention, there is provided a high voltage rotating electric machine as claimed in the ensuing claims 9 and 26.

In use of a rotating electric machine according to the
10 invention there is a considerably reduced thermal stress on the stator and/or rotor. Temporary overloads of the machine thus become less critical and it will be possible to drive the machine at overload for a longer period of time without running the risk of damage arising. This means considerable
15 advantages for owners of power generating plants who are forced presently, in case of operational disturbances, to switch rapidly to other equipment in order to ensure the delivery requirements laid down by law.

With a rotating electric machine according to the
20 invention, maintenance costs can be significantly reduced because transformers and circuit breakers do not have to be included in the system for connecting the machine to the power network.

To increase the power of a rotating electric machine,
25 it is known that the current in the ac coils should be increased. This has been achieved by optimizing the quantity of conducting material, that is, by close-packing of rectangular conductors in the rectangular rotor slots. The aim was to handle the increase in temperature resulting from
30 this by increasing the quantity of insulating material and using more temperature-resistant and hence more expensive insulating materials. The high temperature and field load on the insulation has also caused problems with the life of the

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insulation. In the relatively thick-walled insulating layers which are used for high-voltage equipment, for example impregnated layers of mica tape, partial discharges, PD, constitute a serious problem. When manufacturing these 5 insulating layers, cavities, pores, and the like, will easily arise, in which internal corona discharges arise when the insulation is subjected to high electric field strengths. These corona discharges gradually degrade the material and may lead to electric breakdown through the insulation.

10 The present invention is based on the realisation that, an increase in power of a rotating electrical machine in a technically and economically justifiable way, is achieved by ensuring that the electrical insulation is not broken down by the phenomena described above. This can be achieved by 15 extruding layers of a suitable solid insulating material resulting in the electric field stress being less than 0.2 kV/mm in any gaseous space in or around the electrical insulation. The electrical insulation may be applied in some other way than by extrusion, for example by spraying, figure 20 moulding, compression moulding, injection moulding or the like. It is important, however, that the insulation should have no defects through the whole cross section and should possess similar thermal properties.

Conveniently the electrically insulating intermediate 25 layer comprises solid thermoplastics material, such as low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethylpentene (PMP), cross-linked materials, such as cross-linked polyethylene (XLPE), or rubber insulation, such as ethylene 30 propylene rubber (EPR), ethylene butyl acrylate copolymer rubber, an ethylene-propylene-diene monomer rubber (EPDM) or silicone rubber. The semiconducting inner and outer layers may comprise similar material to the intermediate layer but with conducting particles, such as particles of carbon black 35 or soot, embedded therein. Generally it has been found that a particular insulating material, such as EPR, has similar

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mechanical properties when containing no, or some, carbon particles.

The semiconducting inner layer is preferably electrically connected to, so as to be at substantially the same electric potential as, the superconducting means.

The semiconducting outer layer is preferably connected to a controlled electric potential, preferably earth potential. Connection to the controlled potential is preferably made at spaced apart locations along the length of the outer layer.

In the present specification the term "semiconducting material" means a material having a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an insulator. For example, the semiconducting inner and outer layers may have a resistivity within the interval 1 to 100 k Ω -cm. By using only insulating layers which may be manufactured with a minimum of defects and, in addition, providing the insulation with an inner and an outer semiconducting layer, it can be ensured that the thermal and electric loads are reduced. The intermediate layer should preferably in close contact with, and preferably be adhered to, the inner and outer layers. Conveniently the various layers are extruded together.

The electrically conducting means preferably comprises superconducting means. In this case the conducting means conveniently comprises central tubular support means for conveying cryogenic coolant fluid, e.g. liquid nitrogen, in which case the superconducting means is of elongate form and is wound around the tubular support means. The superconducting means may comprise low temperature superconductors, but most preferably comprises high-temperature (high- T_c) superconducting (or HTS) materials, for example HTS wires or tape helically wound on the tubular support means. A convenient HTS tape comprises silver-sheathed BSCCO-2212 or

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BSCCO-2223 (where the numerals indicate the number of atoms of each element in the $[\text{Bi}, \text{Pb}]_2 \text{Sr}_2 \text{Ca}_2 \text{Cu}_3 \text{Ox}$ molecule) and hereinafter such HTS tapes will be referred to as "BSCCO tape(s)". BSCCO tapes are made by encasing fine filaments of the oxide superconductor in a silver or silver oxide matrix by a powder-in-tube (PIT) draw, roll, sinter and roll process. Alternatively the tapes may be formed by a surface coating process. In either case the oxide is melted and resolidified as a final process step. Other HTS tapes, such as TiBaCaCuO (TBCCO-1223) and YBaCuO (YBCO-123) have been made by various surface coating or surface deposition techniques. Ideally an HTS wire should have a current density beyond $j_c \sim 10^5 \text{ Acm}^{-2}$ at operation temperatures from 65 K, but preferably above 77 K. The filling factor of HTS material in the matrix needs to be high so that the engineering current density $j_e \geq 10^4 \text{ Acm}^{-2}$. j_c should not drastically decrease with applied field within the Tesla range. The helically wound HTS tape is cooled to below the critical temperature T_c of the HTS by a cooling fluid, preferably liquid nitrogen, passing through the tubular support means.

The electrically insulating material may be applied directly over the conducting means. Alternatively thermal expansion means may be provided to cater for differences in coefficients of thermal expansion between the conducting means and the electrically insulating material. For example, a space may be provided between the conducting means and the surrounding electrical insulation, the space either being a void space or a space filled with compressible material, such as a highly compressible foamed material. The thermal expansion means reduces expansion/contraction forces on the insulation system during heating from/cooling to cryogenic temperatures. If the space is filled with compressible material, the latter can be made semiconducting to ensure electrical contact between the semiconducting inner layer and the conducting means.

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Other designs of conducting means are possible, the invention being directed to high voltage rotating electric machines having at least one winding formed of cooled electrically conducting means, preferably comprising cooled
5 superconducting means of any suitable design having a surrounding electrical insulation of the type described above. The plastics materials of the electrical insulation ensure that the winding can be flexed to a desired shape or form at least when at ambient temperatures. At cryogenic
10 temperatures, the plastics materials are generally rigid. However the winding can be made into a desired form within the stator/rotor slots at ambient temperatures before cryogenic cooling fluids are used to cool the conducting means.

Preferably the adjoining electrical insulation layers
15 should have essentially the same coefficients of thermal expansion. At temperature gradients, defects caused by different temperature expansion in the insulation and the surrounding layers should not arise. The electric load on the material decreases as a consequence of the fact that the
20 semiconducting layers around the insulation will constitute equipotential surfaces and that the electrical field in the insulating part will be distributed relatively evenly over the thickness of the insulation.

The outer layer may be cut off at suitable locations
25 along the length of the cable and each cut-off partial length may be directly connected to a chosen electric potential.

Other knowledge gained in connection with the present invention is that increased voltage load leads to problems with electric field (E) concentrations at the corners at a
30 cross section of a coil and that this entails large local loads on the electrical insulation there. Likewise, the magnetic field (B) in the teeth of the stator will, in the case of increased current load, be concentrated at the corners. This means that magnetic saturation arises locally
35 and that the magnetic core is not utilized in full and that

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the waveform of the generated voltage/current will be distorted. In addition, eddy-current losses caused by induced eddy currents in the conductors, which arise because of the geometry of the conductors in relation to the magnetic field B, will entail additional disadvantages in increasing current densities. A further improvement of the invention is achieved by making the coils and the slots in which the coils are placed essentially circular instead of rectangular. By making the cross section of the coils circular, these will be surrounded by a constant magnetic field B without concentrations where magnetic saturation may arise. Also the electric field E in the coil will be evenly distributed over the cross section of the electrical insulation and local loads on the electrical insulation are considerably reduced. In addition, it is easier to place circular coils in slots in such a way that the number of coil sides per coil group may increase and an increase of the voltage may take place without the current in the conductors having to be increased. The reason for this is that the cooling of the conductors is facilitated by, on the one hand, a lower current density and hence lower temperature gradients across the electrical insulation and, on the other hand, by the circular shape of the slots which entails a more uniform temperature distribution over a cross section.

25 An advantage of using a rotating electric machine according to the invention is that the machine can be operated at overload for a considerably longer period of time than is usual for such machines without being damaged. This is a consequence of the design of the machine and the limited thermal load of the electrical insulation. It is, for example, possible to load the machine with up to 100% overload for a period exceeding 15 minutes and up to two hours.

As synchronous compensators there are used, inter alia, synchronous motors without a connected mechanical load. By adapting the magnetisation, the synchronous condenser may give either inductive or capacitive kVA. When the compensator is

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connected to a power network, it may compensate for inductive or capacitive load on the network within an interval. Since the synchronous compensator must be connected to certain power networks with voltages exceeding about 20 kV via a transformer, the range of the synchronous compensator within which it may provide the network with reactive power is influenced by the fact that the reactance of the transformer limits the angle of lag between current and voltage. With a rotating electric machine according to the invention, it is possible to design a synchronous compensator which may be connected to a power network without an intermediate transformer and which may be operated with a chosen under- or over-excitation to compensate for inductive or capacitive loads on the network.

A rotating electric machine according to the invention can be connected to one or more system voltage levels. This is possible because the electric field outside the machine can be kept to a minimum.

The connection to different system voltage levels can be provided by having separate tapplings on one winding or by having a separate winding for the connections to different system voltage levels or by combinations of these arrangements.

Preferably, cables with a circular cross section are used. Among other things, to obtain a better packing density, cables with a different cross section may be used. To build up a voltage in the rotating electric machine, the cable is arranged in several consecutive turns in slots in the magnetic core. The winding can be designed as a multi-layer concentric cable winding to reduce the number of end winding crossings. The cable may be made with tapered insulation to utilize the magnetic core in a better way, in which case the shape of the slots may be adapted to the tapered insulation of the winding.

A significant advantage of a rotating electrical machine according to the invention is that the electric field E is

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near zero in the end winding region outside the semiconducting outer layer and that with the outside of the insulation at earth potential, the electric field need not be controlled. This means that no field concentrations can be obtained, neither within sheets, in end winding regions or in the transition in between.

The present invention also enables a winding to be manufactured by placing the winding in the slots by threading a cable into the openings in the slots in the magnetic core. Since the cable is flexible, it can be bent, prior to operation, e.g. at cryogenic temperatures, and this permits a cable length to be located in several turns in a coil. The end windings will then consist of bending zones in the cables. The cable may also be joined in such a way that its properties remain constant over the cable length. This method is considerably simpler than state of the art methods. The so-called Roebel bars are not flexible but must be preformed into the desired shape. Impregnation of the coils is also an exceedingly complicated and expensive technique when manufacturing rotating electric machines today.

Thus to sum up, a rotating electric machine according to the invention provides a considerable number of important advantages over corresponding prior art machines. Firstly, it can be connected directly to a power network at all types of high voltage. High voltage in this respect means voltages exceeding 10 kV and up to the voltage levels which occur for power networks, such as 400 kV to 800 kV or higher. Another important advantage is that a chosen potential, for example earth potential, is consistently conducted along the whole winding, which means that the end winding region can be made compact and that support means at the end winding region can be applied at practically ground potential or any other chosen potential. Still another important advantage is that oil-based insulation and cooling systems disappear. This means that no sealing problems may arise and that the dielectric ring previously mentioned is not needed. One advantage is

also that all forced cooling can be made at earth potential. A considerable space and weight saving from the installation point of view is obtained with a rotating electric machine according to the invention, since it replaces a previous
5 installation design with both a machine and a step-up transformer. The invention preferably makes use of superconducting means. Since a step-up transformer can be avoided, the efficiency of the system is considerably increased.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawing, in which:

15 Figure 1 is a schematic sectional view of a cable used in a winding of a high voltage rotating electric machine according to the invention; and

Figure 2 is an axial end view of a sector/pole pitch of a magnetic circuit of a high voltage electric machine according to the invention.

20 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows one type of superconducting cable 2 for use in a winding of a high voltage rotating electric machine according to the present invention. The cable 2 comprises elongate inner superconducting means 3 and outer electrical
25 insulation 4. The elongate inner superconducting means 3 comprises an inner metal, e.g. copper or highly resistive metal or alloy, support tube 31 and an HTS wire 32 wound helically around the tube 31 and embedded in a layer 33 of semiconducting plastics material. The electrical insulation
30 4 is arranged outwardly of, at a small radial spacing 34 from, the layer 33. This electrical insulation 4 is of unified form

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and comprises an inner semiconducting layer 35, an outer semiconducting layer 36 and, sandwiched between these semiconducting layers, an insulating layer 37. The layers 35-37 preferably comprise thermoplastics materials which are preferably solidly connected to each other at their interfaces but which could be in close mechanical contact with each other. Conveniently these thermoplastics materials have similar coefficients of thermal expansion and are preferably extruded together around the inner superconducting means. Preferably the layers 35-37 are extruded together to provide a monolithic structure so as to minimise the risk of cavities and pores within the electrical insulation. The presence of such pores and cavities in the insulation is undesirable since it gives rise to corona discharge in the electrical insulation at high electric field strengths.

The semiconducting outer layer 36 is connected at spaced apart regions along its length to a controlled electric potential, e.g. earth or ground potential, the specific spacing apart of adjacent earthing points being dependent on the resistivity of the layer 36 although when placed in winding slots of a core the "earthing points" should be at the end winding at the end of the slots.

The semiconducting layer 36 acts as a static shield and as an "earthed" outer layer which ensures that the electric field of the superconducting cable is retained within the solid insulation between the semiconducting layers 35 and 36. Losses caused by induced voltages in the layer 36 are reduced by increasing the resistance of the layer 36. However, since the layer 36 must be at least of a certain minimum thickness, e.g. no less than 0.8 mm, the resistance can only be increased by selecting the material of the layer to have a relatively high resistivity. The resistivity cannot be increased too much, however, else the voltage of the layer 36 mid-way between two adjacent controlled voltage, e.g. earth, points will be too high with the associated risk of corona discharges occurring.

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The radial spacing 34 provides an expansion/contraction gap to compensate for the differences in the thermal coefficients of expansion (α) between the electrical insulation 4 and the inner superconducting means 3 (including 5 the metal tube 31). The spacing 34 may be a void space or may incorporate a foamed, highly compressible material to absorb any relative movement between the superconductor and insulation system. The foamed material, if provided, may be semiconductive to ensure electrical contact between the layers 10 33 and 35. Additionally or alternatively, metal wires may be provided for ensuring the necessary electrical contact between the layers 33 and 35.

The HTS wire 32 is cooled to cryogenic temperatures by the passage of a cooling fluid, e.g. liquid nitrogen, through 15 the tube 31.

By way of example only the semiconducting plastics material of each of the layers 33, 35 and 36 may comprise, for example, a base polymer, such as ethylene-propylene copolymer rubber (EPR) or ethylene-propylene-diene monomer rubber 20 (EPDM), and highly electrically conductive particles, e.g. particles of carbon black embedded in the base polymer. The volume resistivity of these semiconducting layers, typically about 20 ohm·cm, may be adjusted as required by varying the type and proportion of carbon black added to the base polymer. 25 The following gives an example of the way in which volume resistivity can be varied using different types and quantities of carbon black.

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<u>Base Polymer</u>	<u>Carbon Black</u> <u>Type</u>	<u>Carbon Black</u> <u>Quantity (%)</u>	<u>Volume</u> <u>Resistivity $\Omega \cdot \text{cm}$</u>
Ethylene vinyl acetate copolymer/ nitrite rubber	EC carbon black	~15	350-400
" "	P-carbon black	~37	70-10
" "	Extra conducting carbon black, type I	~35	40-50
" "	Extra conducting black, type II	~33	30-60
Butyl grafted polyethylene	" "	~25	7-10
Ethylene butyl acrylate copolymer	Acetylene carbon black	~35	40-50
" "	P carbon black	~38	5-10
Ethylene propene rubber	Extra conducting carbon black	~35	200-400

The HTS wire 32 may suitably comprise a core of an alloy of superconducting material sheathed in an electrically conductive outer layer, e.g. of silver or silver alloy. Typical of such an HTS wire are silver-sheathed BSCCO-2212 or BSCCO-2223.

To optimise the performance of a rotating electric machine, the design of the magnetic circuit, and in particular the core slots and core teeth is of critical importance. As mentioned above, the slots should connect as closely as possible to the casing of the coil sides. It is also desirable that the teeth at each radial level are as wide as possible to minimise the losses in, the magnetization requirement, etc., of the machine.

Figure 2 shows an axial end view of a sector/pole pitch 6 of a rotating electric machine according to the invention. The rotor with the rotor pole is designated 7. In conventional manner, the stator is composed of a laminated core of sector-shaped laminations. From a yoke portion 8 of the core, located radially outermost, a number of teeth 9 extend radially inwards towards the rotor 7 with slots 10

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formed between the teeth 9. Cables 1 are wound in the slots 10 to form windings in the slots. The use of such cables allows among other things the depth of the slots for high-voltage machines to be made larger than has been possible according to the state of the art. The slots conveniently each have a cross section which decreases, typically but necessarily, in steps or sections towards the rotor (i.e. the slots become narrower towards the rotor) since the need for cable insulation becomes less for each turn or layer of the winding positioned closer to the air gap between the rotor and the stator. As is clear from Figure 2, each slot in radial section substantially consists of spaced apart portions 12 of circular cross section in which the winding layers or turns are received and narrower waist portions 13 linking the portions 12. The slot cross section may be referred to as a "cycle chain slot". In the embodiment shown in Figure 2, cables with three different dimensions of the cable insulation are used, arranged in three correspondingly dimensioned sections 14, 15 and 16. Figure 2 illustrates that the stator teeth can be shaped with a practically constant width in the circumferential direction throughout the radial extent.

The cable 1 can be made in three different joined together sections for reception in the different slot sections 14, 15 and 16. Preferably adjacent cable sections are joined together at cable joints positioned outside, e.g. at one end of, a slot. Typically in a cable joint, the inner support tubes are welded together and the superconducting wire or tape wound therearound are joined together, e.g. by soldering. Typically the joint is surrounded by solid, void-free polymeric material, e.g. of similar polymeric material to that used for the electrical insulation.

The scope of the invention accommodates a large number of alternative embodiments, depending on the available cable dimensions as far as insulation and the outer semiconductor layer etc. are concerned. Also embodiments with so-called

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cycle chain slots can be modified differently to what has been described above.

As mentioned above, the magnetic circuit may be located in the stator and/or the rotor of the rotating electric machine. However, the design of the magnetic circuit will largely correspond to the above description independently of whether the magnetic circuit is located in the stator and/or the rotor.

Each winding may preferably be described as a multilayer, concentric cable winding. Such a winding implies that the number of crossings at the end windings has been minimised by placing all the coils within the same group radially outside one another. This also permits a simpler method for the manufacture and the threading of the stator winding in the different slots.

Although the present invention is primarily directed to rotating machines having at least one winding with conducting means with superconducting properties which are cooled to superconducting temperatures in use, the invention is also intended to embrace rotating machines in which at least one of the windings has conducting means exhibiting improved electrical conductivity at a low operating temperature, up to, but preferably no more than, 200 K, but which may not possess superconducting properties at least at the intended low operating temperature. At these higher cryogenic temperatures, liquid carbon dioxide can be used for cooling the conducting means.

The invention is generally applicable to rotating electric machines for voltages exceeding 10 kV. Rotating electric machines according to what is described under the "Technical Field" are examples of rotating electric machines for which the invention is applicable.

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The electrical insulation surrounding the inner conducting means of a winding of a high voltage rotating electric machine according to the invention is intended to be able to handle very high voltages and the consequent electric and thermal loads which may arise at these voltages. By way of example, such electric machines may have a rated power from a few hundred kVA up to more than 1000 MVA and with a rated voltages ranging from 3-4 kV up to very high transmission voltages of 400-800 kV. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation of a winding of a rotating electric machine according to the present invention is reduced by ensuring that the inner layer of the insulation is at substantially the same electric potential as the inner electrically conducting means and the outer layer of the insulation is at a controlled, e.g. earth, potential. Thus the electric field in the intermediate layer of insulating material between the inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. Furthermore, by having materials with similar thermal properties and with few defects in the layers of the insulating material, the possibility of PD is reduced at a given operating voltages. The windings of the machine can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

Although it is preferred that the electrical insulation surrounding the inner conducting means of a winding of a high voltage rotating electric machine according to the invention should be extruded in position, it is possible to build up an electrical insulation system from tightly wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner.

An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties and can be combined with a superconducting pipe as an electric conductor and have coolant, such as liquid nitrogen, pumped through the pipe.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil or liquid nitrogen can be used.

In this specification "semiconducting material" means a substance which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an electric insulator. Suitably, but not essentially, the semiconducting material will have a resistivity of $1-10^5$ ohm·cm, preferably 10-500 ohm·cm and most preferably from 10 to 100 ohm·cm, typically 20 ohm·cm.

CLAIMS

1. A high voltage rotating electric machine comprising a stator (6), a rotor (7) and at least one winding (1) wound on the stator having inner electrically
5 conducting means (3) and surrounding electrical insulation (4), characterised in that said electrically conducting means comprises conductor means (32) and cooling means (31) for cooling the conductor means (32) to improve the electrical conductivity of the conductor means, and in that
10 said electrical insulation (4) is solid and comprises spaced apart inner and outer layers (35, 36) each having semiconducting properties and, between said inner and outer layers, an intermediate layer (37) of electrically insulating material.

2. An electric machine according to claim 1, characterised in that the said semiconducting inner layer (35) is electrically connected to, so as to be at substantially the same electric potential as, the conductor means (32).

3. An electric machine according to claim 1 or 2, characterised in that the said semiconducting outer layer (36) is connected to a controlled electric potential along its length.

4. An electric machine according to claim 3, characterised in that the said semiconducting outer layer (36) is connected to said controlled electric potential at spaced apart regions along the length of the outer layer.

5. An electric machine according to claim 3 or 4, characterised in that the said controlled electric potential
30 is earth potential.

6. An electric machine according to claim 5, characterised in that, with connection of the semiconducting outer layer (36) to earth potential, the electric field of

the machine both in winding slots (10) and in end winding regions will be near zero.

7. An electric machine according to claim 3 or 4, characterised in that the electric machine has more than one winding wound on the stator and in that a separate controlled potential is selected for each winding.

8. An electric machine according to any one of the preceding claims, characterised in that at least one of said semiconducting inner and outer layers (35, 36) has substantially the same coefficient of thermal expansion (α) as that of the said insulating layer (37).

9. An electric machine according to any one of the preceding claims, characterised in that each pair of adjacent layers (35-37) of said electrical insulation are secured to each other along substantially their entire contact surfaces.

10. An electric machine according to any one of the preceding claims, characterised in that the or each winding is in the form of a cable (1).

11. An electric machine according to any one of the preceding claims, characterised in that the said conductor means (32) comprises superconducting means.

12. An electric machine according to claim 11, characterised in that the cooling means comprises central tubular support means (31) for conveying cryogenic coolant fluid, e.g. liquid nitrogen, and in that the superconducting means (32) is of elongate form and is wound around the tubular support means.

13. An electric machine according to claim 11 or 12, characterised in that the said superconducting means comprises high-transition temperature superconducting (or HTS) material.

14. An electric machine according to claim 12, characterised in that the said electrically conducting material comprises HTS tape or wire wound on a tubular support means (31).

5 15. An electric machine according to any one of the preceding claims, characterised in that thermal expansion means (34) are provided between the said electrically conducting means (3) and the said surrounding electrical insulation (34).

10 16. An electric machine according to claim 15, characterised in that said thermal expansion means comprises an expansion gap (34).

15 17. An electric machine according to claim 16, characterised in that the expansion gap (34) comprises a void space.

18. An electric machine according to claim 16, characterised in that the expansion gap (34) is filled with compressible material, e.g. foamed plastics material.

20 19. An electric machine according to claim 18, characterised in that the said compressible material includes electrically conductive or semiconductive material.

20. An electric machine according to any one of the preceding claims, characterised in that thermally insulating means is provided outwardly of the conducting means.

25 21. An electric machine according to any one of the preceding claims, characterised in that the or each winding is wound in stator slots (10) formed in the stator, and in that each stator slot (10) comprises a number of substantially circular cylindrical openings (12) extending
30 axially and radially outside one another, each pair of adjacent openings (12) being joined by a narrower waist portion (13).

ing to claim 13 when

22. An electric machine according to claim 13, characterised in that the radii of the said conductors around said each stator slot decrease in a direction towards the center of the

5 (7).

23. An electric machine according to any one of the preceding claims, characterised in that the rotating electric machine is connectable to one or more system voltage levels.

10 24. An electric machine according to claim 23, characterised in that one winding is provided with separate windings for connection to different system voltage levels.

15 25. An electric machine according to claim 23 or 24, characterised in that a separate winding is provided for connection to each system voltage level.

26. An electric machine according to any one of the preceding claims, characterised in that the said intermediate layer (37) is in close mechanical contact with each of said inner and outer layers (35, 36).

20 27. An electric machine according to any one of claims 1 to 25, characterised in that the said intermediate layer (37) is joined to each of said inner and outer layers (35, 36).

25 28. An electric machine according to claim 27, characterised in that the strength of the adhesion between the said intermediate layer (37) and each of the semiconducting inner and outer layers (35, 36) is of the same order of magnitude as the intrinsic strength of the material of the intermediate layer.

30 29. An electric machine according to claim 26 or 28, characterised in that the said layers (35-37) are joined together by extrusion.

30. An electric machine according to claim 29, characterised in that the inner and outer layers (35, 36) of semiconducting material and the insulating intermediate layer (37) are applied together over the conducting means
5 (3) through a multi layer extrusion die.

31. An electric machine according to any one of the preceding claims, characterised in that said inner layer (35) comprises a first plastics material having first electrically conductive particles dispersed therein, said
10 outer layer (36) comprises a second plastics material having second electrically conductive particles dispersed therein, and said intermediate layer (37) comprises a third plastics material.

32. An electric machine according to claim 31,
15 characterised in that each of said first, second and third plastics materials comprises an ethylene butyl acrylate copolymer rubber, an ethylene-propylene-diene monomer rubber (EPDM), an ethylene-propylene copolymer rubber (EPR), LDPE, HDPE, PP, PB, PMP, XLPE, EPR or silicone rubber.

33. An electric machine according to claim 31 or 32,
20 characterised in that said first, second and third plastics materials have at least substantially the same coefficients of thermal expansion.

34. An electric machine according to claim 31, 32 or
25 33, characterised in that said first, second and third plastics materials are the same material.

35. An electric machine according to any one of the preceding claims, characterised in that it is designed for use at high voltages, suitably in excess of 10 kV, in
30 particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

36. An electric machine according to any one of the preceding claims, characterised in that it is designed for use at a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

5 37. Use of a rotating electric machine according to any one of the preceding claims, characterised in that the machine can be operated with up to 100% overload for a period of time exceeding 15 minutes and up to about two hours.

10 38. Use of a rotating electric machine according to any one of claims 1 to 36, characterised in that the rotating electric machine is directly connected to a power network via connecting devices and without an intermediate transformer between the machine and the network.

15 39. Use of a rotating electric machine according to any one of claims 1 to 36, characterised in that voltage regulation of the rotating electric machine is performed by control of the magnetic field flow through the rotor.

20 40. Use of a rotating electric machine according to any one of claims 1 to 36, characterised in that the machine can be operated without mechanical load and that the machine is provided for compensation of inductive or capacitive load on the network.

Fig. 1

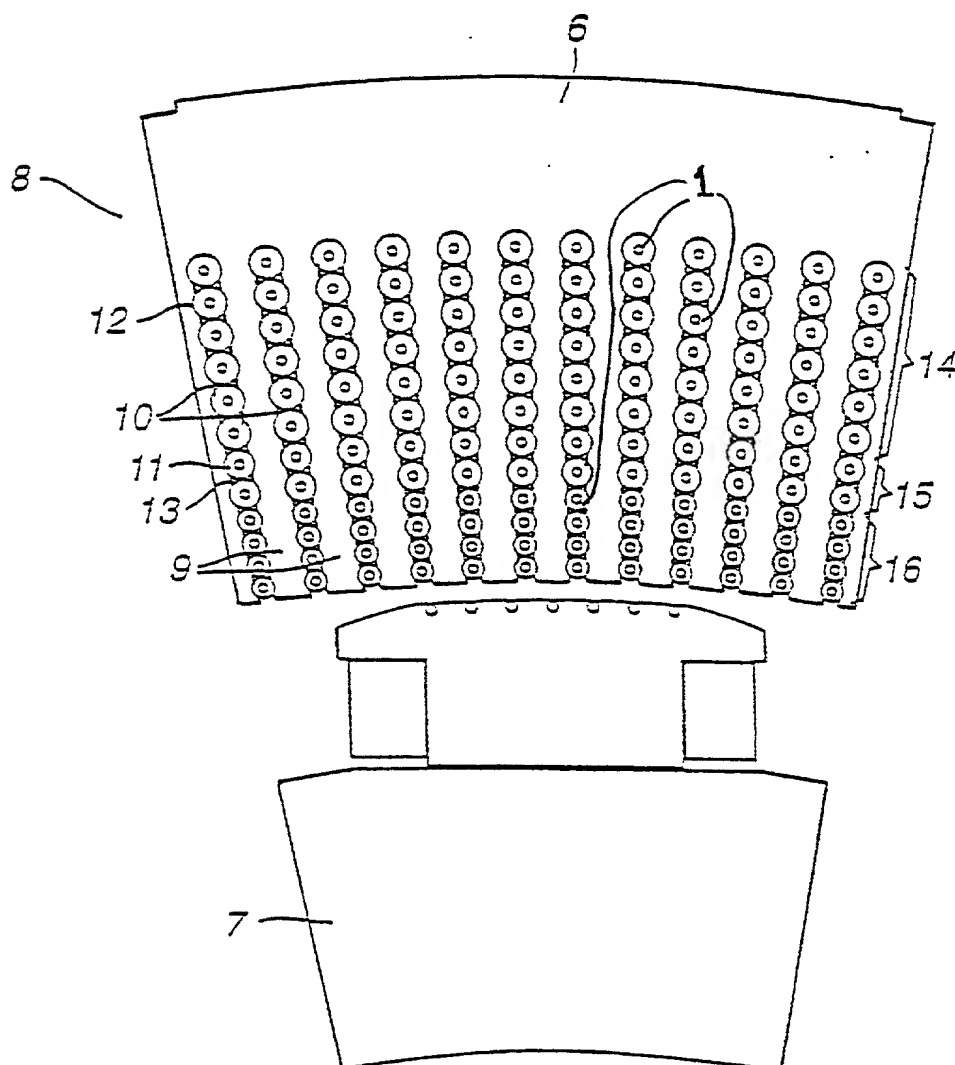
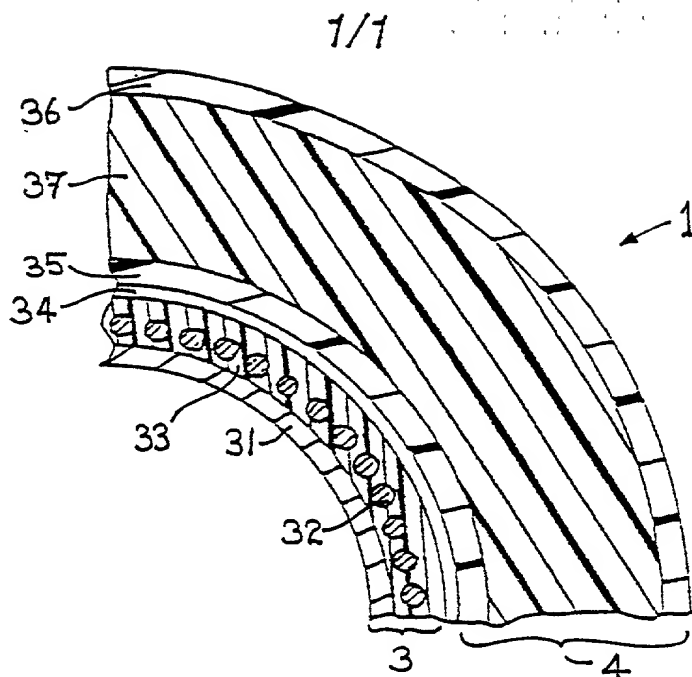


Fig. 2

Fig. 1

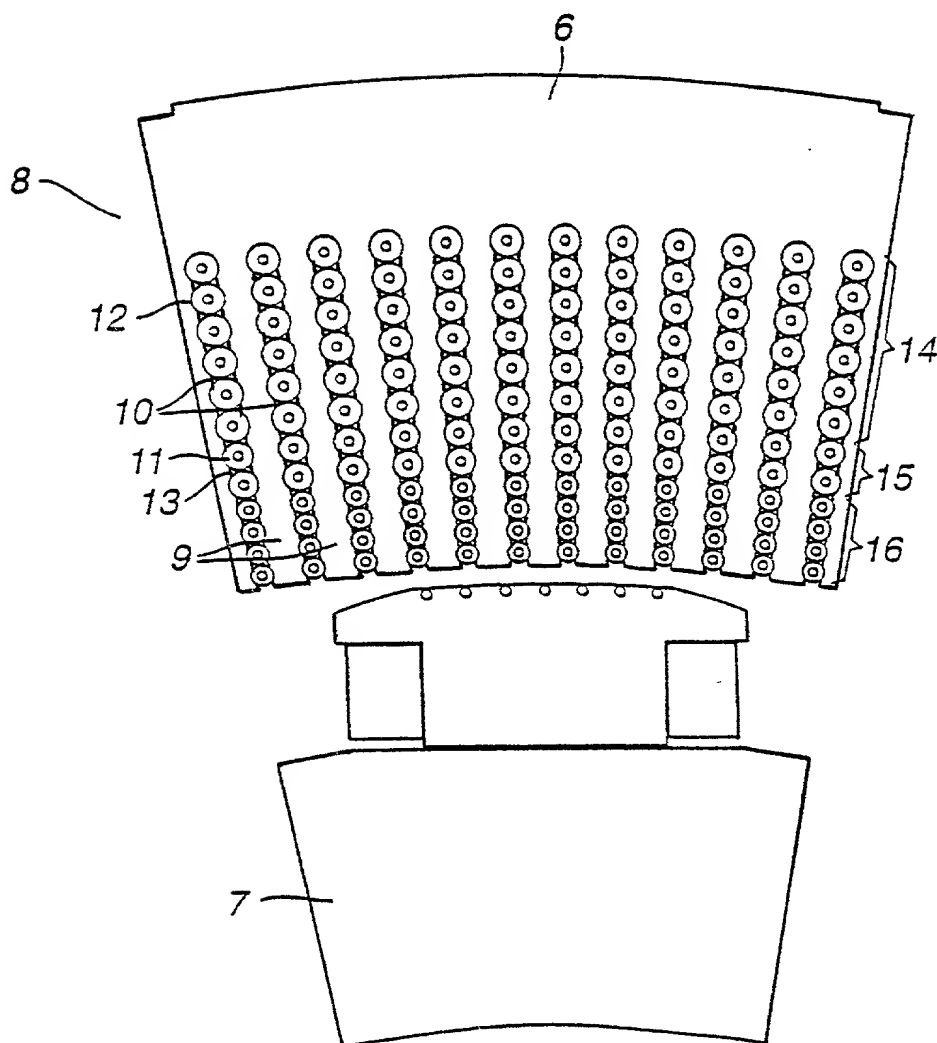
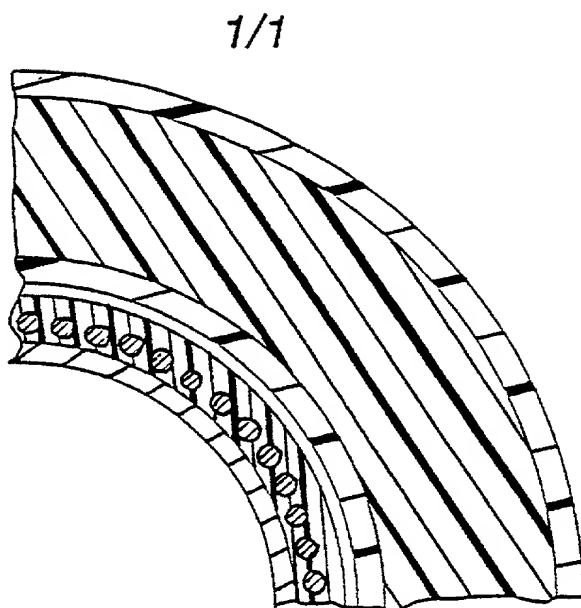


Fig. 2

8357 us

Declaration, Power Of Attorney and Petition

Page 1 of 2

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

HIGH VOLTAGE ROTATING ELECTRIC MACHINES

the specification of which

☐ is attached hereto.

☒ was filed on 22 May 2000 as

Application Serial No. _____

and amended on _____.

☒ was filed as PCT international application

Number PCT/EP98/07738

on 30 November 1998,

and was amended under PCT Article 19

on _____ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed	
<u>9725316.5</u>	<u>GREAT BRITAIN</u>	<u>28 November 1997</u>	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

<u> </u> (Application Number)	<u> </u> (Filing Date)
<u> </u> (Application Number)	<u> </u> (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.


Application Serial No.	Filing Date	Status (pending, patented, abandoned)
<u>PCT/EP98/07738</u>	<u>30 November 1998</u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; Vincent J. Sunderdick, Reg. No. 29,004; William E. Beaumont, Reg. No. 30,996; Robert F. Gnuse, Reg. No. 27,295; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Robert W. Hahl, Reg. No. 33,893; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; Paul E. Rauch, Reg. No. 38,591; William T. Enos, Reg. No. 33,128; and Michael E. McCabe, Jr., Reg. No. 37,182; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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Signature of Inventor

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28 June 2000
Date